Validation of Positive Fraction Vector Fitting Algorithm in the identification of Passive Immittances

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Abstract: The paper deals with the problem of identification of guaranteed passive rational models for linear distributes structures. The identification is pursued in two separate steps: in the first step the Vector Fitting algorithm is used for the identification of the poles; then the identification of residues is formulated as a convex programming problem with constraints on single terms of the pole-residue expansion. This approach, although suboptimal, is easier than constraining passivity on the whole transfer function, and at the same time more rigorous than perturbative approaches. In the paper the procedure is validated in reference cases and comparatively evaluated vs. other existing passivity enforcement schemes.

Keywords: Frequency domain identification, electronic systems macro-modeling, passivity enforcement

I INTRODUCTION

A large number of electrical and electronic systems consist of linear distributed passive electromagnetic structures interacting with lumped elements (possibly non linear). Their system level analysis and design is largely based on circuit simulation. An important example of such situation is the modeling of electrical interconnects in order to address several signal integrity issues; other examples can be found in the area of modeling of electrical power systems etc. It is well known how frequency domain lumped equivalent macro-models of such structures can be derived through the identification of a "black box" rational approximation of the transfer matrix. Quite a large body of research has been dedicated recently to the development of efficient and robust identification techniques in the frequency domain (see review in [1]), and the problem is considered to be satisfactory solved by the Vector Fitting algorithm [2-3].

In order to get stable time domain system level simulations the passivity of the identified sub-systems should be guaranteed. Although the theoretical conditions for checking-enforcing passivity on rational models are well established [4], different schemes for implementing the identification of passive rational models are available, whose advantages and disadvantages are still controversial [5-8]. Enforcing passivity in rational models can be pursued with two "in principle" different approaches. The most common is to check passivity after a complete identification step has been applied, then opportunely perturbing the solution to correct possible passivity violations. A second, more robust approach is to formulate the identification problem keeping the passivity as an a-priori constraint [8], based on necessary and sufficient conditions. Unfortunately this latter approach is of unaffordable computational burden as complexity of the system under identification became realistic.

In this paper we validate a new "mixed" approach recently proposed in [9], which conjugates the advantages of the VF algorithm for the poles identification, leaving the residue identification to a second step consisting in a convex programming problem with constraints on single terms of the pole-residue expansion.

II. PASSIVE IDENTIFICATION

We deal with the identification of a passive immittance $Y(s)$ or $Z(s)$ from frequency domain data samples $\{\omega_k, \tilde{Y}(j\omega_k)\}_{k=1..K}$. The Vector Fitting (VF) algorithm is well known as a valid approach to pursue such identification of problem, but it can not guarantee that $Y(s)$ is a Positive Real function (i.e. it represents a passive system). When after the identification passivity violations are detected, passivity is usually enforced via perturbation-based approaches [5-7], locally correcting the identified model around those frequencies where passivity violations are found. The main drawback of this scheme is that it usually degrades the accurate approximation found by VF, and some time diverges destroying the identification at all.

A direct identification of a state space realization of a passive immittance can be formulated as a convex programming problem by exploiting the *Positive Real lemma*, which provides a necessary and sufficient condition for the passivity of a system [4]. The main issue in this case is that the optimization algorithm has to handle a large additional set of variables. Therefore, due to the increased complexity, the identification is limited to quite low order systems. In order to reduce the number of variables in the optimization step, a custom mathematical formulation was pursued in [8].

An alternative approach named Positive Fraction Vector Fitting (PFVF) has been recently proposed for the identification of a transmission line reduced model in [9], essentially based on separately enforcing passivity on each term in the VF pole-residue expansion. We consider the immittance function $Y(s)$ in the form:

$$Y(j\omega) = a_0 + \sum_{n=1}^{N_r} \frac{a_n}{j\omega - p_n} + \sum_{n=1}^{N_c} \left(\frac{b_n j\omega + c_n}{-\omega^2 + d_n j\omega + e_n} \right), \qquad (1)$$

where the poles (and corresponding coefficients $\{p_n, d_n, e_n\}$) are supposed to have been already identified with any suitable procedure (i.e. VF). Then the residue identification step is pursued solving the optimization problem (with respect the quantities $\{a_n, b_n, c_n\}$):

$$\arg\min_{\{a_n, b_n, c_n\}} \sum_{k=1}^{K} |Y(j\omega_k) - \tilde{Y}(j\omega_k)|^2 \qquad \begin{array}{l} a_n \geq 0 \quad \text{for } n = 1 \ldots N_r \\ \begin{cases} b_n d_n - c_n \geq 0 \\ c_n \geq 0 \end{cases} \quad \text{for } n = 1 \ldots N_c \end{array} \qquad (2)$$

This optimization approach reveals to be easier then those based on the Positive Real lemma, since it does not introduce new variables. On the other hand it may lead to sub-optimal solutions.

A validation scheme of the described procedure can be cast by the identification of a data set with intrinsic passivity violations, as well as passive data flawed by noise. We consider, for the data generation, a generic order N dynamic circuit where random parameters are assigned with the possibility of passivity violations and the possible addition of random noise. In figure 1a is reported an example of such an admittance frequency response of order 15 with some passivity violation intervals. In figure 1b we show the results of the PFVF identification, which enforces correctly passivity without a significant degradation of accuracy as compared to VF.

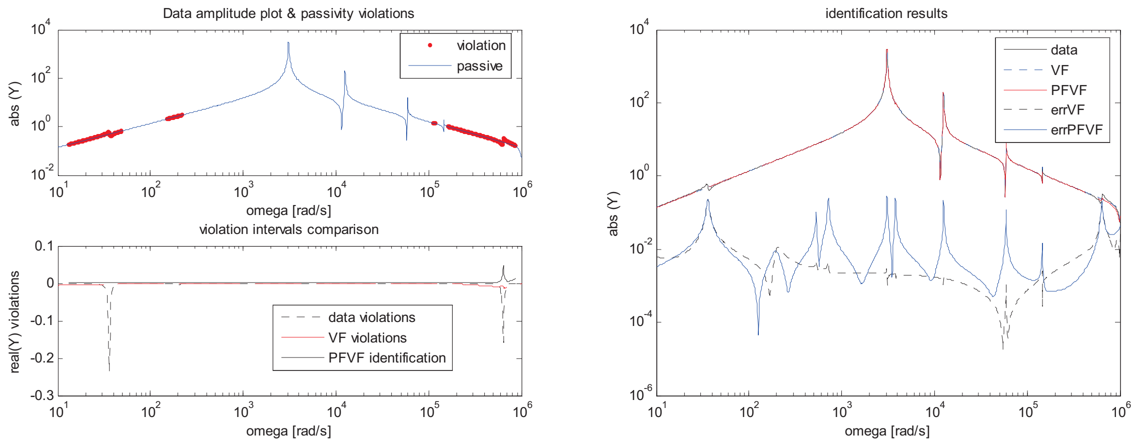

Fig. 1: a) frequency plot of data and passivity violations; b) identified curves and identification error

A complete validation of the PFVF will be given with the characterization of the robustness of the algorithm versus the degree of passivity violation and the amplitude of violation intervals, etc. Moreover the procedure will be tested with real study cases, comparing the result with existing passivity enforcement techniques.

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